DESIGN AND DEVELOPMENT OF MAGNETORHEOLOGICAL FLUIDS FOR ACTIVE SUSPENSION IN DAMPING APPLICATIONS

SYNOPSIS

Submitted by

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(Reg. No. 201715131)

in partial fulfilment for the award of the degree of

DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICS

SCHOOL OF ADVANCED SCIENCES

KALASALINGAM ACADEMY OF RESEARCH AND EDUCATION

(DEEMED TO BE UNIVERSITY)

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TAMIL NADU, INDIA

FEBRUARY 2023

1. INTRODUCTION

Smart Materials are distinctive and noticeable because of their change in characteristic qualities. Magnetorheological Fluid (MRF) is one most interesting class of smart materials which accepts magnetic field as an external stimulus. The main function of MR Fluid is its ability to change the state of matter from fluid to semi solid when an external magnetic field is applied (i.e visible change in viscosity within microseconds. The fluid possesses a non-magnetic liquid along with field-responsive particles, that support magnetic saturation when exposed to a magnetic field. During magnetization, the molecules in the fluid get oriented by forming chains or cross-links. The continuous occurrence of cross link of the magnetic particles occurs along the applied field direction. These chain-like structures restrict the motion of the fluid, thereby increasing the viscosity. Additives or adsorbents are added in moral to increase the efficiency of the fluid. Several kinds of research are endured with varying the morphology of micron and nanosized magnetic particles like pure soft iron, carbonyl iron, and ferrite particles.

Magnetic Suspension particles with variation in size [1], structure (plate, flake) was considered and better results with good yield stress have been reported [2–5]. Various additives [6,7], thixotropic, lubricant materials like Oleic acid [8], SDBS, emulsifiers, and tween-80 [9], polycarboxylic ether and stearic acid [10,11], fumed silica were incorporated to improve the redispersion ability of particles in fluid. Each component has special features and conditions to perform in efficient mode. MR Fluid's major constituent is carrier fluid. Hydrocarbon oil or mineral oil as carrier fluid is employed more extensive in automobile applications. Soft magnetic particles are best choice among various suspension particles like hard magnetic materials, metal alloys. Being a two-phase magnetic fluid, MRF requires good and easy reverse field-effect properties to avoid prolonged remanent magnetization.

The density imbalance of the base fluid and the particles suspended causes severe sedimentation problems. The aggregation of the suspension particles complicates the life span of the fluid. Therefore, the elements of the MR Fluid are optimized to improve the efficiency of the fluids. Optimization of MR Fluid can be done in two different approaches; one method is to improve the density of the base fluid and the other approach is to functionalize the suspension particles. For the past few

decades, to overcome these defects researchers are working deliberate towards optimisation of MRF in several ways and techniques, such as varying the ratio of suspension particles/additives each in particular and also as whole component, functionalising the particles by encapsulating with capping agent, incorporating surfactants to complete fluid, varying particle system are few techniques mentioning to optimize MRF. The change in viscosity of fluids give hands to potential applications. The major applications include automobile machines, seismic controller in buildings, house applications like washing machines, medical field for drug carrier/tumour approach. Properties of fluid varies with respect to application engineered. MR Dampers (Magnetorheological Dampers) are termed as improvising devices due to their extraordinary real-time controllability features [12,13]. Several damper models have been introduced with the factors that are calculated based in numerical methods and were reported depending on the application requirements [14–16]. The connection of magnetic particles benefits restraining the mechanical vibrations produced in the concerned application. This phase changing property of the fluid stands important as vital principal of several applications naming damping, prosthetics, military armour applications [17].

2. LITERATURE REVIEW

Kumar et al. [18] used CI particles functionalized with natural gum additive to synthesize MRF and reported that the shape of the particles has a significant influence on the fluid. Jahan et al. [19] reported improved dynamic efficiency in bidispersed(two variant sized particles) MR Fluids. Fei et al. [20] discussed about the MR Fluid with various surfactants compounding in different composition and concluded with enacting that 2.8% surfactant fluid shows better properties with significance of mass fraction. Sedimentation of suspended magnetic particles has been optimised by encapsulation i.e., capping magnetic suspension particles technique in a research by Cho et al. [21]. Similarly, various approaches have been taken by researchers to optimize the base fluid density.

Magnetorheological fluid with hydrocarbon oil was investigated and reported by Kalkurar et al. [22], concluding that 35% base oil volume with suspension particles gives higher yield stress. Asiaban et al. [10] used engine oil as a carrier medium and analysed the behavior of MRF at different temperatures and reported improved stability

and sedimentation properties. Ido [23] measured the viscous properties of MRF with Polyalphaolefin base(polymer alkene) and optimized the base fluid density, viscosity subsequently. A phenomenal viscosity model has been synthesized with silicone oil as the carrier fluid by Jung et al. [24] and they have attained good efficiency. Kumbhar et al. [25] developed an MR Fluid using silicone oil as the carrier fluid. Remarkably the yield stress, which is an important factor for MRF was higher in silicone oil based MRF when compared to the conventional synthetic oil MRF. Thomas et al. [26] from Delphi tech., used Synthetic hydrocarbon oil as base fluid and obtained successful results with desirable yield and saturation level. Rabbani et al. [27] published a detailed report on silicon oil and steric acid based MRF with 92% enhanced stability of fluid. Sidpara et al. [28] worked with water and paraffin oil-based MR Fluids, comparing the behavior of MRF with water and paraffin oil as a carrier fluid and determined water-based MRF has high yield stress when compared to the paraffin oil-based MRF. In the same instance, water based MRF has friction developed in it as water do not assist lubricant nature, this develops oxidation prone disadvantage in MRF. Oxidation prone MR Fluid develops roughness in particles and does not support for long shelf life. Few other hydrogenated oils(home used oils) were used by researchers for MR Fluid study. Beside lubricant nature of these oils they did not attain better yield and efficiency.

Rosales et al. [29] gave a detailed suggestion on the parameters required for the optimal application performance. Machacek et al. [30] investigated silicon based MRF and depicted significant improvement in the quality of damping on the account of frictionless damper chosen for their work. Consequently, distinctive research on magnetorheological fluids is enduring due to their significant demand in high ended applications.

3. OBJECTIVE OF THE THESIS

The objectives of this research works are as follows,

- To synthesis a conventional MRF and characterize the rheological property of the fluid.
- To identify and optimize the viscosity of career fluid used in MRF.
- To fabricate efficient MR Fluids for automobile damping application.
- To analyse the rheological, modulus and sedimentation properties of the optimized MR Fluids.

- To study the damping behavior of the synthesized fluids with a semi-active suspension.

4. RESEARCH PROBLEM OF THE THESIS

Magnetorheological Fluid has amazing material properties which ways to innovative damping and controllable applications. Although, the density mismatch of the fluid and particle creates an imbalance and that leads to increase in sedimentation and hardening of the fluid. During the active state Brownian motion is observed in the micro dynamic behavior of the fluid. Whereas the static state of the fluid follows with settling of particles and the inter molecular force is self-induced between the magnetic particles. This leads to agglomeration of particles and small floccules formation occurs. During the phase change in dynamic state this agglomeration of particles creates uneven distribution of the external field force. Particles once settled down forms a coagulated hard substance and this aspect is referred to hard cake. Occurrence of hard cake makes MRF's usage less viable. Hence it is identified that the density of the magnetic particles and base fluid for dispersion can be optimized either. Several techniques have been identified for the functionalization of materials. Magnetic particles can be functionalized by encapsulation method with polymer additives and lubricants. Carrier fluids can be functionalized with addition of thixotropic and lubricants. Several research were reported functionalizing the particles with polymer additives. Few works have been found to be reported based on functionalization of carrier fluids with disparate additive and lubricants.

This research work proposes to synthesize MRF with optimization of carrier fluid by coalescing homogenous lubricant material as an inclusion. The argument of the thesis is to discuss the rheological and damping properties of optimized MRF with standard shear strength and viscous behavior supporting adequate damping property.

5. ORGANIZATION OF THE THESIS

CHAPTER – 1 INTRODUCTION

This chapter primarily explains about the fundamentals and evolution of Magnetorheological Fluids. This smart fluid has strongly impressed and soared the vibrational control research leading to excellent innovation of damping applications and devices. Viscosity as a primary application parameter of MRF makes to fluid's analysis

and study to greater extent as this can resist the vibration encountered and discharges as heat. In view of the importance of viscosity, rheology (i.e) the flow behavior of the fluid is thoroughly analysed for the better performance. The fluid has extensive applications beside damping, including optical polishing for refined glass surfaces and drug delivery systems. This chapter further enfolds fundamentals of rheology and basic rheological fluid laws which is mandatory to understand the data interpretation and analysis.

Chapter 1 is concluded with entire description of the research problem identified. In brief, the major research problem for MRF is the density mismatch which leads to gradual limitations like sedimentation, hardening, deficient redispersibility and floccule formation with vigorous manual redispersion. Based on these limitations, the objectives of the research work were determined and proceeded. The scope of this research work intends automobile damping applications with MR Fluids.

CHAPTER – 2 LITERATURE REVIEW

Chapter 2 describes an elaborate literature survey of MRF and MR applications, devices. It holds handful of research ideas and reports shard with respect to elements of MR Fluids. The chapter is fragmented into 4 sections which delineates the MR Synthesis, Risk factors of MRF, behavioural analysis of MRF and the MR application analysis.

The MR synthesis section explains about each constituent/element's importance and the optimizations performed in the fluid elements for the past two decade. The risk factors, otherwise stated as research problems clearly explains the techniques and suggestions reported by researchers. The section, MR behavioural analysis details about the rheological parameters for observation and analysis to understand the flow and modulus behavior of the fluid. Customization and designing of MR application have been drastically increased lately. The final section hence explains about the application parameter study and the software elemental analysis along experimentation performed by several researchers.

CHAPTER – 3 EXPERIMENTS AND INSTRUMENTATION

In this chapter, the experimental methods and procedures followed is explained in detail. Conventional method to synthesis MRF is done with two basic elements, a

carrier fluid, and the suspension particles. Since we have limitations observed in MR Fluid, optimization techniques are handled. Rheometer supported with varying magnetic field is used for analysis. Response and behavior of the fluid to applied rotating and oscillating shear forces with magnetic field as function are observed.

In secondary portion, the instrumentation for studying the rheology and damping properties is explained in detail. Antonpaar rheometer is used for rheology and modulus behavior analysis. Industrial customized suspension system was used for damping analysis. The system allows varying frequency and magnetic field which was used as functions to determine the damping force of the fluid. The trial-and-error methods carried out to prepare MR Fluids are later discussed in annexure.

CHAPTER 4 – EFFECT OF MAGNETIC FIELD ON THE VISCOUS BEHAVIOUR OF IRON PARTICLES SUSPENDED SILICONE ADDITIVE BASED MAGNETORHEOLOGICAL FLUIDS

In this work, the initial considerations for MR Fluid synthesis are performed. The choice of materials and the proportion are evaluated clearly, and the final efficient synthesized fluid examined for the objective property is studied. The work focuses on procuring progressive yield stress and effective sedimentation stability of MRF by optimizing the preferred base fluid.

The aim of the research work intends on two goals, the primary motive is to fabricate and analyse the MRF with different composition, whereas the second objective relates about optimizing the sedimentation rate of the fluid. Carrier oil, commonly known as the base fluid in MRF is an important lead for the facile physical phase transformation of the fluid. After comparing the properties of various alternative carriers (honge oil, silicon oil, sunflower oil, and castor oil) silicone oil is selected as a carrier liquid in this present work concerning the temperature stability of the material. Soft quality Iron magnetic particles were chosen for suspension particles. Additive thickeners are included in the carrier fluid to reduce the agglomeration of magnetic particles in the fluid. Silicon-based lubricant was induced to carrier fluid through a blending mechanism to maintain homogeneity and prevent lumps in the carrier fluid. Rheological properties and dynamic modulus properties are analysed and studied for the synthesized convention and functional Magnetorheological Fluid. The data observed were interpreted using technical software, Rheoplus and the final objective to

synthesize efficient fluid was achieved with detailed explanation on the significance and choice of the base materials. The obtained data was related with non-Newtonian fluid rheology models and verified with earlier research works reported.

CHAPTER 5 – RHEOLOGICAL PROPERTIES OF MAGNETO - RHEOLOGICAL FLUIDS WITH DIFFERENT BASE FLUIDS AND A COMPATIBLE ADDITIVE

This chapter explains about the research on base fluids and the rheology study on MR Fluids with silicone oil, fork oil and engine oil as carrier fluids. The main aim of this work is to identify the carrier fluids supportable for the MR Fluid. The important and identified base liquids are used for the synthesize of the MR Fluid and the behavior of the fluids in dynamic field is observed repeatedly. Later, the observed results are interpreted and verified for prominent results. The results are then compared with previous works and comprehensive conclusion is reported.

After comparing the properties of various alternative, silicone oil is finalized as an efficient carrier liquid in this present work. Soft Iron magnetic particles were chosen for suspension particles and additive thickeners are included to carrier fluid. Our research work intended in probing the rheological properties and dynamic modulus analysing of the synthesized convention and functional Magnetorheological Fluid. Later, behavior of the obtained data was investigated, verified with earlier work of other researchers, and discussed in this chapter.

CHAPTER – 6 RHEOMETRIC AND STABILITY ANALYSIS OF ADDITIVE INFUSED MAGNETORHEOLOGICAL FLUIDS – A COMPARATIVE STUDY

Following the identification of volume ratio and carried fluid optimization, additive preference has been examined. This research work focuses to incorporate one of the component(additive/surfactants) in the fluid and aims to study the performance of the fluid. Additive and surfactants are blended and manually treated with the fluid components. In this study, MRF is infused with siloxane, lithium, oleic acid and SDBS(Sodium Dodecyl Benzene Sulfonate) as additive and surfactants with silicon oil as a carrier fluid. The rheology behavior of the samples is analysed to study the comparative performance insights of the fluid. Other repercussion factors like temperature and particle sedimentation are also examined and interpreted.

Substantially, the efficient sample and performance is comprehended after an insightful comparative study.

The components of the material have been listed with contextual analysis. Four preferred additives and surfactants were preferred based on their temperature stability and blending capability analysed from literature and research. The fluids were synthesized with silicone, lithium, and oleic acid, SDBS as additive and surfactants respectively. Initially. The rheology properties were examined and the shear strength of the Si-MRF, OA-MRF and Li-MRF were identified definite. The viscosity of the fluid data was interpreted, and the fluids shown shear-thinning behavior with inflation in shear rate. Si-MRF shown gradual behavior with 2.9x104 Pa. s apparent viscosity and 12 Pa. s static viscosity. Thermal stability of the synthesized fluids profoundly depends on the base fluid. Si-MRF depicted superior performance in the rheometric and stability analysis with 55% of sedimentation rate in reason to the homogenous nature of the fluid. Due to the homogenous preferences of carrier and additive components, the fluid has high stability and alleviates from agglomeration phenomena. It is evident that homogenous additive inclusion remarkably mitigates the substantial performance of the fluid at the analysed shear rates.

CHAPTER – 7 ANALYSIS ON MAGNETORHEOLOGY AND DAMPING BEHAVIOR OF SILOXANE ADDITIVE INFUSED MR FLUIDS

The research objective of this work is to examine the damping behavior and efficiency of synthesized MR Fluids. The analysis was performed considering damping force, sedimentation ratio, velocity and frequency of damper, magnetic flux density or current, time as parameters. The inter relation between the sedimentation and the damping property was studied in detail and reported. The factors that affect the damping factor was also discussed and mentioned.

The material composition of the fluid was preferred through repeated experimentations. Several research works have been performed and accomplished to overcome the synthesis and damper characterization of MRF to overcome its defects. We aim to synthesis better sedimentation resistant optimized MR Fluid supporting excellent damping property with primal experimentation. Considered to the proposed hypothesis, siloxane lubricant as an additive is influenced to enhance the sedimentation resistance and redispersion property of the fluid. After the optimization of the fluid,

sedimentation, rheology, and damping properties of synthesized MRF were examined and investigated in the application perspective.

In the end of this chapter, the MR Fluids which were inadequate in efficiency are explained as fallible cases. Detailed causes for the failure in fluids were identified and the methods to overcome was discussed. Few samples shown clear floccule formation during shear analysis and the reports were included. Iron oxides, manganese ferrite and fumed silica were tried as filler particles and the results were not up to expectations. Iron oxide and manganese ferrite samples were prone to oxidation due to foreign particles during the chemical synthesis of materials. Chemical co-precipitation method was followed to synthesize the chosen filler particles. Several additives like PEG, Oleic acid, Tween – 80, 60 and SDBA (Sodium Dodecyl Benzene Sulfonate) were also tried as additives and the shelf life of the sample were observed lower than the above efficient results. Among two functionalization techniques we have chosen to functionalize the carrier liquid. The carrier liquids like castor oil, mineral oil, honge oil were also ended in failure after one year of shelf life. Lithium grease and metallic stearate was considered as one among choice for lubricants other than Siloxane lubricant. Unfortunately, both failed showing heterogenous creamy surface at the bottom of the MR fluid samples. Although hydrogenation prevents oxidation of oils in general fact, the MR Fluid with hydrogenated non-automobile oils resulted on strong agglomeration of particles. This chapter is concluded with ways to overcome the observed inadequacies.

CHAPTER – 8 SUMMARY AND CONCLUSION

This chapter discusses about the overall concept, highlights, and the conclusion of the performed research work. Initially, the objects of the research work were outlined based on the literature studies. Primary work focuses on adapting the ratio and elements of the MR Fluid. It was reported that (this percentage) of Fe particles with (this percentage) of carrier fluid shows efficient rheology results with conducive sedimentation property. Following this studies were executed for optimization of elements. Several research works were identified with functionalization of dispersed magnetic particles. We opted to functionalize the carrier fluid and repeated experimentation was performed to determine the convenient base fluid for MRF. Followed by the practical and literature evaluation, silicone oil was preferred and MR

Fluid with silicone oil blended with silicone additive was analysed to understand the behavior of the fluid. It was observed that homogeneity of the carrier fluid enhances resistance to sedimentation when compared with the other carrier fluid demonstrated. (This percentage) of sedimentation factor was noticed in the data observed. Further, the chosen fluid after proportion evaluation and functionalization was analysed for damping application efficiency. The behavior of the fluid was observed before and after fixed sedimentation test period. It was observed that, the fluid shows commendable damping efficiency with negligible difference in the readings. Beside all the experimental works reported, the fallibility of the fluid was also inferred to avoid failure of the fluid in further research works.

After detailed evaluation of the synthesized MR Fluids, this research concludes with the efficient proportion for MR Fluid with Silicone induced lubricant. Although, several research works were reported in MR Fluid optimization, the novelty of this research work outstands with homogenous choice of carrier fluid material in addition to the specific composition of materials and ratio of MR Fluid. Future work of this research will be continued with customization of damping application device and fabrication of MR Fluid with respective to the property-based need for applications.

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